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MADRE EVALUATION REPORT VII

[UNCLASSIFIED TITLE]

S. R. Curley, W. C. Headrick, J. M. Headrick,
F. H. Utley, J. L. Ahearn, and G. A. Skaggs

Radar Techniques Branch
Radar Division

January 22, 1963

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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"Madre Evaluation Report III," J. M. Headrick, S. R. Curley, M. E. Thorp, J. L. Ahern, F. H. Utley, W. C. Headrick, and D. C. Rohlfs, NRL Memo Report 1316, Feb. 1962 (Secret Report, Unclassified Title)

"Madre Evaluation Report IV," J. M. Headrick, J. L. Ahern, S. R. Curley, E. W. Ward, F. H. Utley, and W. C. Headrick, NRL Report 5811, June 1962 (Secret Report, Unclassified Title)

"Madre Evaluation Report V," S. R. Curley, J. M. Headrick, J. L. Ahern, W. C. Headrick, F. H. Utley, D. C. Rohlfs, and M. E. Thorp, NRL Report 5824, July 1962 (Secret Report, Unclassified Title)

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NRL Report 5881

MADRE EVALUATION REPORT VII

[UNCLASSIFIED TITLE]

DETECTION OF A SUBMARINE-LAUNCHED POLARIS MISSILE VIA THE E-LAYER

[SECRET TITLE]

S. R. Curley, W. C. Headrick, J. M. Headrick,
F. H. Utley, J. L. Ahearn, and G. A. Skaggs

Radar Techniques Branch
Radar Division

January 22, 1963

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT
[Secret]

On May 11, 1962, a Polaris missile, Type A2PE, was launched from a submarine near Cape Canaveral. The Madre radar, located at the Chesapeake Bay Annex of the Naval Research Laboratory, detected the missile from over the horizon during the last twelve seconds before thrust termination. Although backscatter returns were present from both E- and F-layer propagation, a comparison of the measured slant range and the true range, calculated from postflight data, showed that the only possible path was via E-layer.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

NRL Problem R02-23
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MIPR-30-635-8-160-6136

Manuscript submitted November 16, 1962.

MADRE EVALUATION REPORT VII
[Unclassified Title]

DETECTION OF A SUBMARINE-LAUNCHED POLARIS MISSILE VIA THE E-LAYER
[Secret Title]

Madre is a high-frequency, high-power, coherent, doppler radar located at the Chesapeake Bay Annex of the U. S. Naval Research Laboratory. It has been in operation for several months and has been used to detect rocket-powered missile launches from the Atlantic Missile Range (AMR).

In ordinary use, Madre's energy is refracted by the ionosphere (F layer) so that it illuminates the missile path close to the launch site, and below-the-horizon detection can be obtained. Attempts to illuminate the launch site itself via F-layer propagation during a launch have been unsuccessful to date because of the proximity of the Madre site to AMR launch sites (1200 km); that is, the combination of the current low sunspot period (or low ionospheric electron density) and the minimum-frequency capability of Madre has resulted in placement of one-hop energy beyond the site. However, under normal daytime ionospheric conditions, the energy can be made to intercept some portion of the trajectory of a missile close to the launch site. On a number of occasions missiles have been detected and identified as missiles when they were as low as 80 km altitude. A line-of-sight path from the Madre site would place a beam about 130 km over the launch site.

Details of the Madre radar can be found in a number of publications. One of these is NRL Memo. Report 1251, Dec. 1, 1961, "A Madre Evaluation Report" (Secret Report, Unclassified Title). For the purpose of affording a better understanding of the figures, a partial description of the system will be given here.

The received signals are synchronously detected and then passed through a set of comb rejection filters which reject the ordinary backscatter clutter by rejecting the repetition – rate frequency and all of its harmonics plus a few cycles on either side of these frequencies. The doppler frequency from each target will appear around zero frequency and around the repetition-rate frequency and its harmonics. Also, although recede and approach doppler frequencies can be resolved, this was not done for the test in this report; therefore, around zero frequency and around the repetition-rate frequency and its harmonics, both increasing and decreasing dopplers can appear.

The repetition rate for the test in this report was 90 cps. In Fig. 1, only the doppler frequency associated with zero frequency appears, since only zero to 45 cps are displayed. In Fig. 2, where zero to 90 cps are displayed, the increasing doppler associated with zero frequency and the decreasing doppler associated with 90 cps are displayed. The missile was known to be receding at the time.

The pertinent parameters for the Madre radar during this test were as follows:

Frequency	23.1 Mc
Repetition Rate	90 pps
Power Radiated	60 kw (average)
Pulse Width	500 μsec
Antenna Gain	15 db one way
Antenna Bearing	190 degrees.

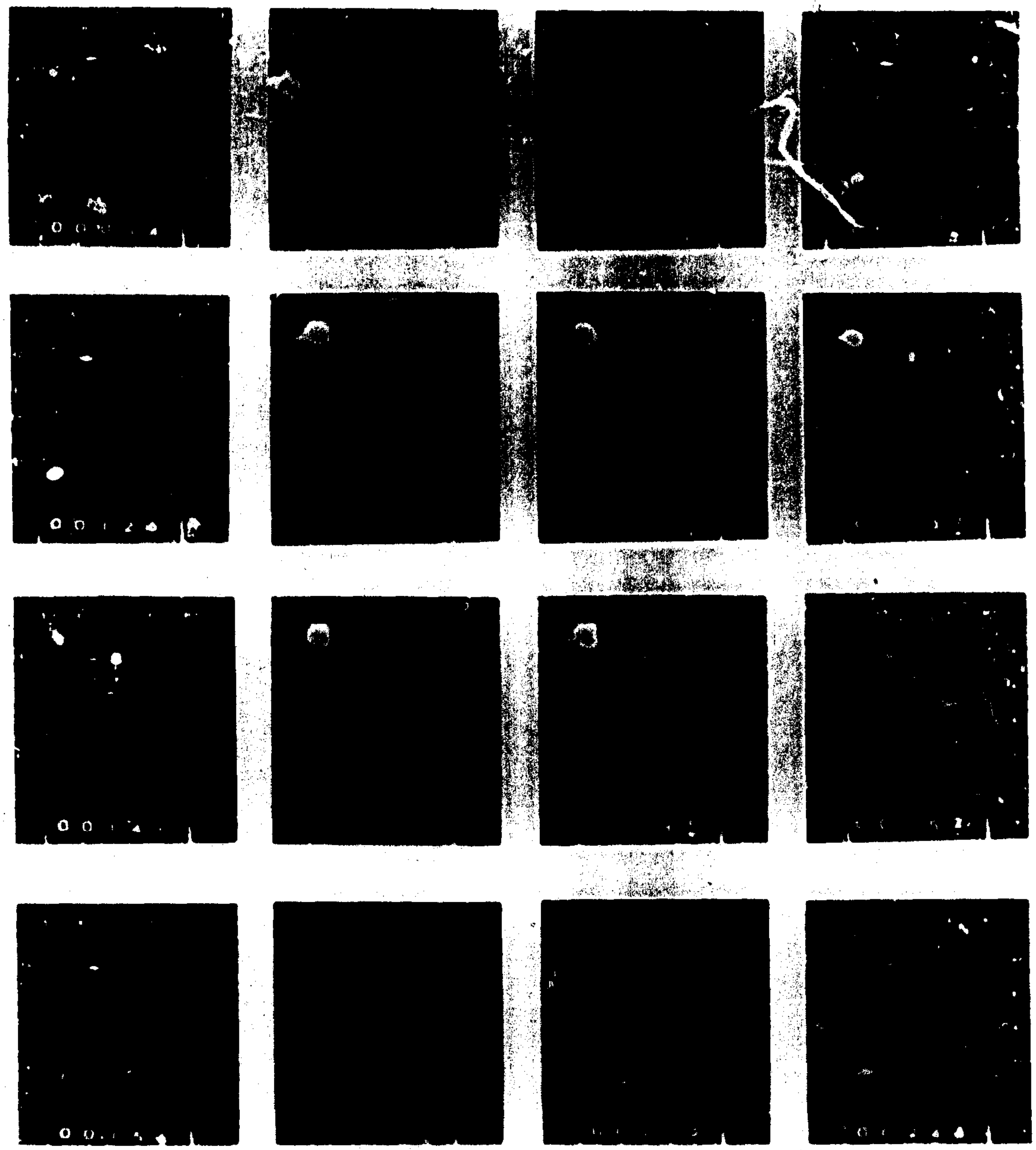

Fig. 1 - Consecutive photographs of the Madre real-time display shortly after launch. The appropriate ordinate is at the left and represents the doppler frequency in cycles per second. The abscissa is at the top and represents slant range in naut mi. The system calibration signal is located at 610 naut mi in range and at 40 cps in doppler. The bright spot in the upper left hand corner in frames 6 to 11 is a light leak. Time is indicated at the bottom of each frame. The missile signature appears in the sixth frame at 675 naut mi range and at 30 cps doppler and disappears by frame 13.

Fig. 2 - Vibragram showing the doppler frequencies versus time of the signature obtained from AMR test 3001. The ordinate represents frequency in cycles per second. The abscissa represents the time in seconds after launch.

AMR Test No. 3001 (formerly AMR Test No. 0081) was a submarine-launched Polaris missile, type A2PE-4. It was launched on May 11, 1962, at 1826 Z. Postflight data did not give the thrust termination time nor height, but preflight data gave these as T_0 + 105 sec and 103 km.

Ionogram information transmitted over the Tepee net before launch time indicated strong E-layer blanketing. Backscatter returns from the direction of the launch site indicated both E and F propagation. Figure 3 is a photograph of backscatter returns on the Madre receiver i-f shortly after launch. Total sweep time corresponds to 3600 naut mi. The first patch of backscatter appears between 450 and 1300 naut mi and is undoubtedly due to the sporadic E indicated by the ionograms. The second patch of backscatter runs from about 1500 to 1800 naut mi and is undoubtedly due to F layer. The remainder of the backscatter is second-hop F layer.

Figure 4 is the ionogram received from the SRI OHD Data Center. Using this ionogram and the secant relationship, and extrapolating to the operating frequency of 23.1 Mc, backscatter can be expected to appear between 496 and 1240 naut mi from the sporadic E layer, and between 1480 and 1900 naut mi for the F layer.

It should be pointed out here that the present Madre positionable antenna imposes limitations in determining the direction from which the backscatter returns originate. The antenna beamwidth is approximately 40 degrees, which in itself is a limiting factor. In addition, the antenna cannot be rotated when radiating full power. Because of time limitations, it is rarely desirable to go through a detailed procedure of fixing the directions from which the various patches of backscatter reach their maxima. During a countdown, conditions often change radically, and sometimes there is a question as to whether or not the preflight missile trajectory is being illuminated. Also, with the present Madre radar complex a frequency shift is a time-consuming operation, so that where backscatter returns indicate that a frequency shift is desirable, the time required may be considered prohibitive, especially if the countdown has proceeded to a late stage. It is emphasized that these difficulties are not inherent. Such equipment limitations exist in the interest of economy.

Just before T_0, an equipment failure caused Madre to shut down, and it was not operating again until T_0 + 83 sec.

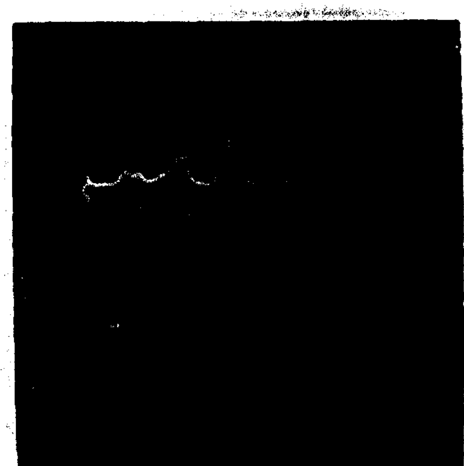

Fig. 3 - Amplitude versus range presentation of the backscatter returns at the 500-kc i-f shortly after launch. The amplitude (ordinate) scale is relative. The range (abscissa) scale represents 3600 naut mi of slant range. The signal at zero range represents one or more local scatter targets. Backscatter returns via E-layer commence at 450 naut mi and end at 1300 naut mi. Backscatter returns via F-layer commence at 1500 naut mi and end near 1800 naut mi. The backscatter returns beyond 1800 naut mi are due to second-hop F-layer propagation.

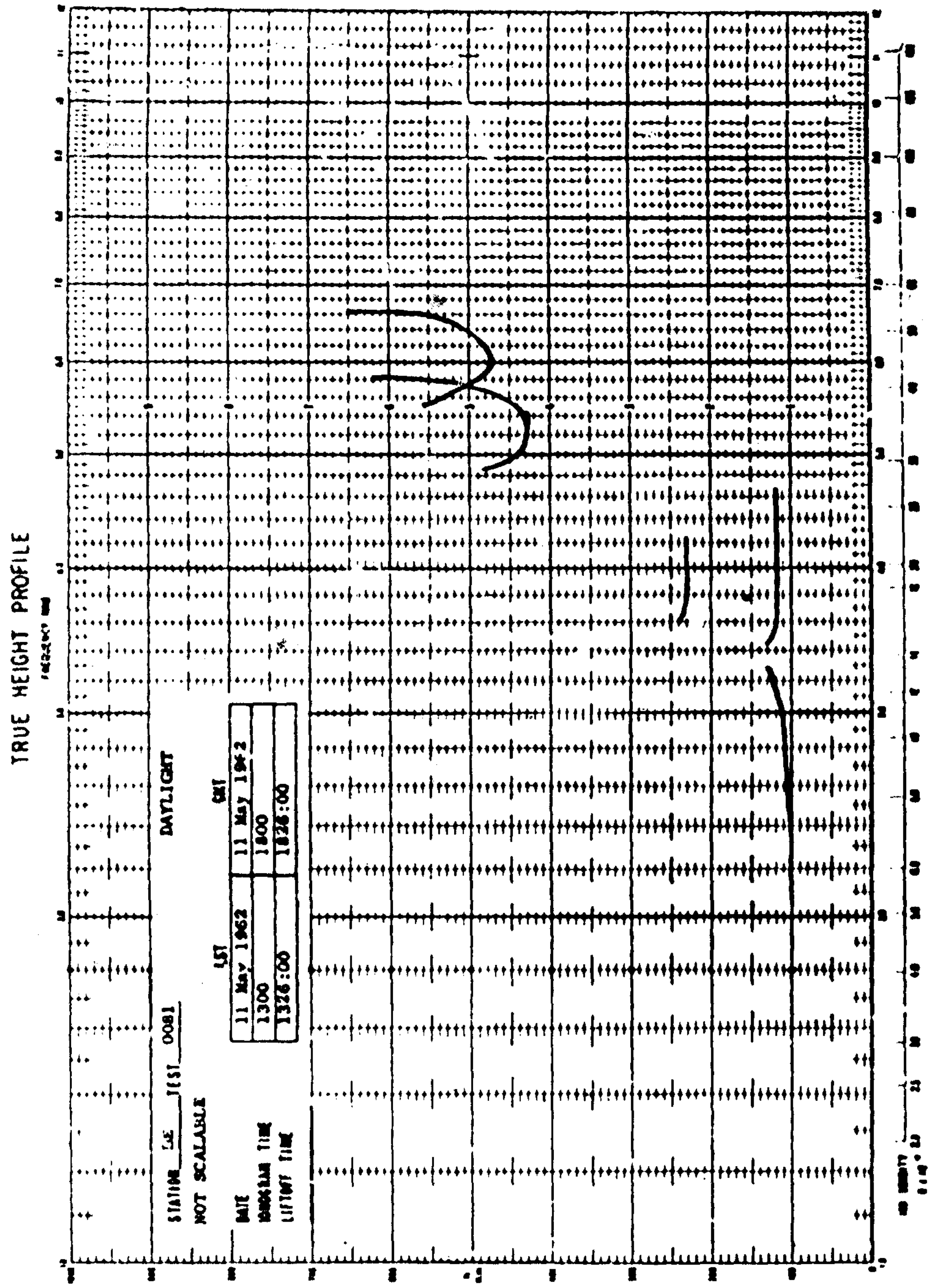

Fig. 4 - Ionogram received from SRI. The ordinate represents virtual height in kilometers. The abscissa represents frequency in megacycles per second.

In Fig. 1 are consecutive photographs of the Madre real-time display during the launch period. For this case the ordinate is on the left of each picture and the abscissa is at the top. The ordinate represents the doppler frequencies in cycles per second. Since the repetition rate during the test was 90 cps, only 45 cps of unambiguous doppler frequencies are available. The abscissa represents the range in nautical miles. At the bottom of each picture is given the time after T_0 in minutes and seconds; for example, 00034 is T_0 + 34 seconds, while 00134 is T_0 + 1 minute and 34 seconds. At the time the pictures were taken, the timer had a constant error of four seconds, so four seconds should be added to each time indication to give the correct time. The persistent signal at an indicated range of 610 naut mi and at 40 cps doppler frequency is the system calibration signal. Its amplitude is one microvolt peak to peak at the receiver input, and the true range is 600 naut mi. Therefore all targets will be displaced by 10 naut mi from the indicated range. The large bright signal in the upper left-hand corner from the 6th frame to the 11th frame is a light leak from the photograph equipment.

The target is first seen in the sixth frame at 675 naut mi and at 39 cps doppler; the time is 1 minute 30 seconds. With the indicated corrections inserted, the time would be T_0 + 1 minute 34 seconds at 665 naut mi. A calculation made from the postflight data places the missile at an altitude of 80 km at this time. The target grows in intensity and spreads out in doppler in the succeeding frames. It is finally gone in frame 13, so the target disappears between T_0 + 1 minute 56 seconds and T_0 + 2 minutes. According to preflight data, the target was to burn out T_0 + 1 minute 45 seconds. The integration time of the Madre analysis system accounts for the persistence of the signal after this time.

Figure 2 is a vibragram of the same signal taken from the receiver output before passing through the Madre analysis system. The ordinate is frequency and the abscissa is time. Recede and approach dopplers are not resolved here, so both decreasing and receding dopplers will appear and be symmetrical around 45 cps. The straight lines appearing at 30 cps and 60 cps are the usual 60-cps lines caused by the equipment: the former is the 60 cps related to the repetition rate, and the latter is the 60-cps line related to zero frequency, since the 60-cps line will appear on both sides of the repetition rate and its harmonics.

The target first appears at T_0 + 92 seconds as a discrete signal (Fig. 2), then spreads out in frequency until it disappears abruptly at T_0 + 104 seconds. This is the time of thrust termination predicted from preflight data. At T_0 + 92 seconds, the missile is 80 km in altitude. The range of this signal was determined to be 665 ± 5 naut mi, from the A-scope presentation.

The altitudes of the missile for the duration of the signal are well below line of sight from the Madre location, so the signal was obtained via refraction. From the ionogram it is evident that the normal E layer, located at 100-km height, could not be the main refracting medium, since (a) it is too low in height and (b) it is too low in electron density for 23.1 Mc. Over the past year Madre backscatter returns have been compared many times with current ionograms from various locations, and E-layer returns are never present (at any Madre frequency) whenever the E-layer frequency is below 3.5 Mc. The same studies show, however, that E-layer returns are almost always present at all Madre frequencies (13.5 to 27 Mc) whenever the E-layer frequency exceeds 4.5 Mc. Figure 4 shows that the sporadic E fits this case and that its height is adequate to account for the signal obtained. F-layer returns are from far beyond the missile position and cannot account for the signature.

Although this is the first report dealing with a Polaris detection from Madre radar, it is not the first or the only Polaris detection made by Madre. It was felt that the mode of propagation, via sporadic E, justified a detailed treatment of this particular test.

Madre has obtained a Polaris signature for every occasion on which the backscatter indicated that the powered portion of the trajectory was being illuminated. In all, ten detections have been made, in which the Polaris has been at various altitudes from 80 km to the thrust-termination altitude. Discrete doppler information has been extracted for those cases where the detection was made below 95 km, thus indicating the missile velocity at the time of the signature. The potential for extracting discrete doppler information for other types of missiles has been demonstrated.

These tests and others, including all types of missiles launched from AMR, will be included in a report which is now in preparation.

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20 February 1997

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